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Relationship of cosmic ray diurnal anisotropy and high speed solar wind streams

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Abstract : It is accepted that high speed solar wind streams originated from the sun can be identified into two categories . the coronal hole associated or corotating streams (CS) and flare-generated streams. In this analysis, we examine the effects of these two types of solar wind streams on diurnal anisotropy of cosmic ray daily variation for the period of 1980-1982 Amplitudes and time of maxima (Phases) of diurnal vectors have been obtained from harmonic analysis, using the hourly counts of Deep River neutron monitor. The daily vectors have been obtained for the intervals, before, during and after each event of high speed solar wind streams on the basis of chree and vector addition analysis It has been found that the solar flare-generated high speed solar wind streams are most effective to produce isotropic and anisotropic changes in cosmic ray intensity. We observe relatively smaller amplitude of the diurnal anisotropy during the period of flare-generated streams.

Keywords : Cosmic rays/solar wind/diurnal variation

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1. Introduction

It is well known that the high speed Solar wind Steams can be separated into two categories : The coronal hole associated highspeed solar wind Streams or corotating streams (CS) and the flare-generated high speed solar wind streams (FGS). These separations are based on the basis of their velocity, variational profiles, proton temperature, density and fluctuation in magnetic field [1]. It has been observed that the Flare-generated Streams (FGS) associated with Sudden Storm Commencement (SSC) produce large forbush type decreases in cosmic ray intensity on short term basis [2,3]. Besides these transient variations, it has also been observed that the anisortropies in cosmic ray daily variation show changes in its ampititudes and Time of maxima (Phases) on day to day basis as well as on long-term basis [4–7].

It was observed in one of the earlier investigations that the high speed solar wind stream ejected from coronal holes, produce large amplitudes in cosmic ray diurnal variation [4,5]. Rigidity dependence was also reported as one of important factor in cosmic ray diurnal variation during the period of high speed solar wind streams and it is also found that the rigidity dependence is more sensitive around 50 GV [8]. Significant day to day changes in diurnal vectors and solar wind streams are recently reported during the period of Forbush-decreases [9].

Theoretically, we know that the cosmic ray anisotropies are produced by the Solar modulation with period of 24 hours and its harmonic upto a certain limiting energy. Diurnal variation of cosmic ray anisotropies can be explained on the basis of diffusion-convection theory and in this theory, variation of cosmic ray depends on the Solar wind velocity, which generates an outward radial convection of cosmic ray particles and their inward diffusion along the interplanetary field. This mechanism was being considered before 1970, to explain diurnal variation theoretically. In the steady State of equilibrium condition, the particle must rigidly corotate with Interplanetary magnetic field, thereby generating an energy independent anisotropic flow from the 18-hr corotation direction with an amplitude in space $\approx$ 0.6% [10].

In the present paper, we analyse the characteristics of diurnal anisotropy during the periods of flare-generated Streams as well as corotating Streams to observe the behaviour of diurnal amplitude and phase in relation to these two types of high speed Solar wind Streams.

2. Method of analysis

We have separated the two types of high speed Solar wind streams into two categories, Flare-generated Streams (FGS) and Corotating Streams (CS) on the basis of similar criteria as reported by Mavromichalki in 1988 [1]. Following Physical features are considered for the identification of Corotating Streams : (i) Proton density rises to unusually high values near the leading edges of the streams, (ii) The interplanetary Magnetic field (B) magnitude is proportional to bulk speed with a constant polarity throughout the Stream and (iii) The proton temperature varies in a pattern similar to that of the flow speed.

Flare-generated Streams are selected on the following criteria.

(I) All the Interplanetary parameters show simultaneous increases.

(II) The proton temperature behaviour tends to depart from the speed behaviour.

(III) The proton density, bulk speed and magnitude show large fluctuations in the maximum speed period.

Adopting the above criteria and using the plots of hourly values of interplanetary parameters [11,12], we select the 19 corotating streams and 15 Flare-generated streams for the period of 1980-1982, which also satisfy the following conditions.

(I) The Solar wind speed should remain at high values (500 Kms^{-1}) at least three days after it begins to increase.

(II) No Forbush Decrease (FD) of magnitude ≥ 3% in cosmic ray intensity should occur during –5 to +10 days of the starting day of high speed Solar wind Streams. Purpose of this restriction is to avoide their influence on the result of this analysis. We have done harmonic analysis to obtain day to day amplitude and Time of maximum (Phase), for five days earlier from the event, event days, and five days after the event using the high counting rate neutron monitor data of Deep River station. (1.02 GV).

3. Results and discussion

Past studies have indicated the changes in anisotropies of daily variation of cosmic ray intensity during the disturbed as well as in Quiet interplanetary conditions. In earlier studies, it has been observed that these changes are must. Low average amplitude in diurnal

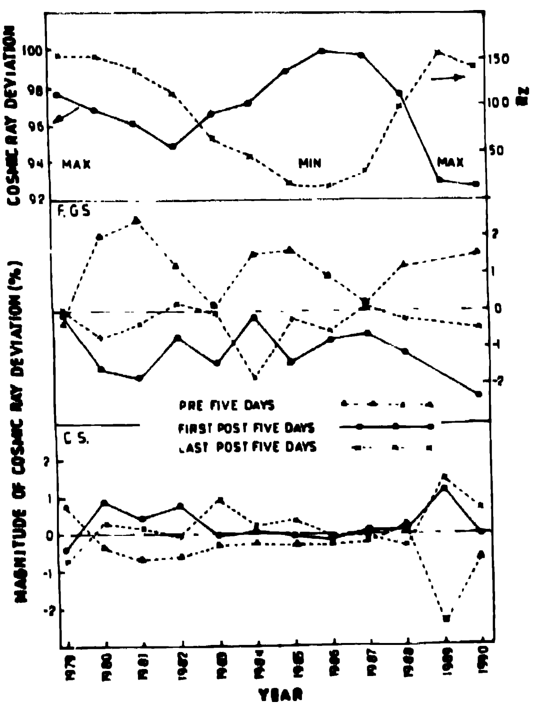

Figure 1. Long-term linear diagram which shows magnitude of cosmic ray deviation in three categories : (I) Pre five days from starting day of high speed solar wind streams, (II) First post five days from zero days, (III) Last post five days from zero days yearly mean values of Tokyo neutrons and Sun spot

anisotropy has been reported during the Quiet interplanetary medium [13,14]. Here, we have done a systematic study to observe the average daily anisotropy in two different conditions of disturbed interplanetary medium, which are represented by two different kinds of high speed Solar wind Streams, because the high speed Solar wind Streams are good indicators of disturbed interplanetary medium. Solar wind one of the important parameters is convection-diffusion drift model produce modulation in cosmic rays [15]. In principle, it has been expected that enhancement in Solar wind velocity certainly affects the daily vectors of cosmic rays. Several studies in past which confirmed the transient variations in cosmic ray intensity on short-term basis, initiated us to observe variational characteristics of most significant diurnal vectors of cosmic ray daily variational.

Figure 1 shows the magnitude of cosmic ray deviations, which are plotted for periods of corotating and Flare-generated Streams, in two different blocks. These magnitudes are shown in three different categories : (i) Pre-five days from starting day (zero day) of high speed Solar wind Streams, (ii) First post five days after zero day, (iii) Last five days after zero day. Yearly averages of cosmic ray intensity for Tokyo neutron monitor (11.50 GV), along with sunspot numbers are also plotted at the top of Figure 1, for the long interval of 1979 to 1990. Middle part of figure shows large magnitude of decreases during certain intervals such as 1980–1982, 1984–1986. It is remarkable that Flare-generated Streams produce maximum magnitude of decreases during the interval 1980–1982, which cover the high Solar activity period of sunspot cycle 21. Hence, we have selected the interval (1980–1982) suitable for anisotropic analysis. Figure 2 shows the results of Chree analysis for diurnal vectors of the daily variation, during the period of corotating streams. Zero day is taken as the starting day of high speed solar wind streams.

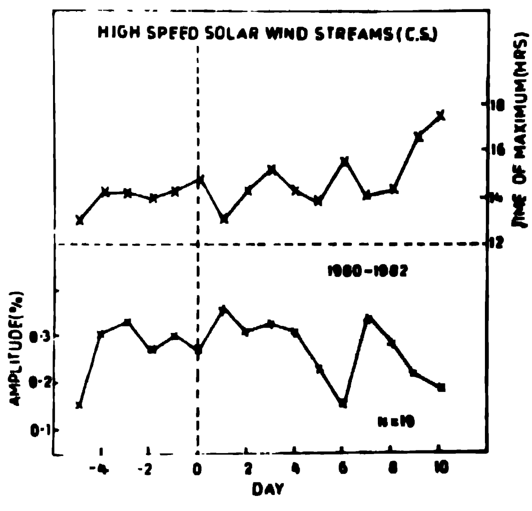

Figure 2. The results of chree analysis of superposed epoch from –5 to +10 days with respect to zero epoch days. Zero days correspond to starting day of high speed solar wind streams. Amplitudes and phases are derived from harmonic analysis, using the hourly values of Deep River neutrons for the pre, event and post periods of corotating streams.

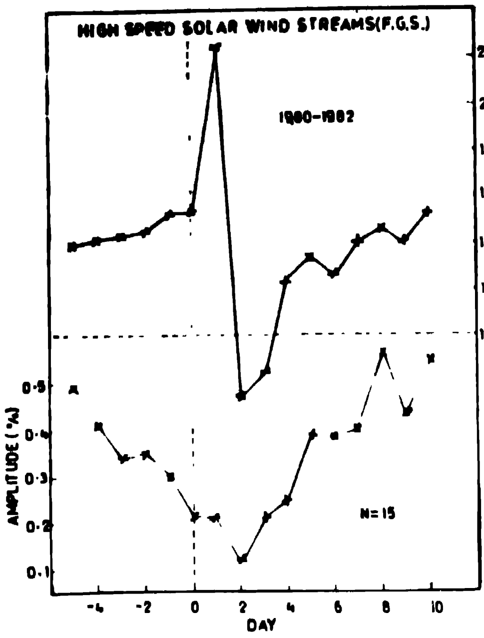

Figure 3. Same as Figure 2 for Flare-generated streams.

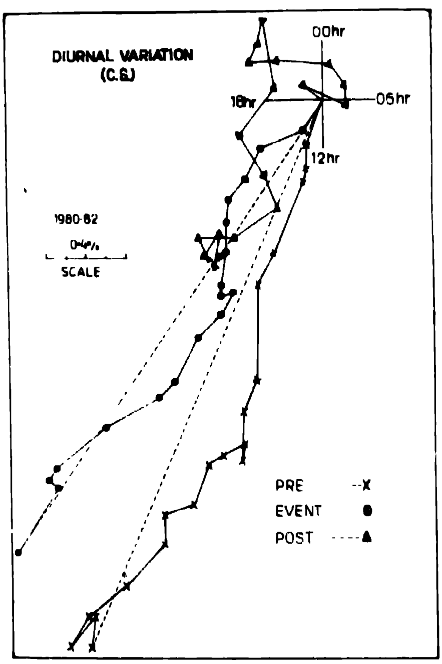

Figure 4. The vector addition diagram of diurnal components for the years 1980-1982 as explained in the text. The pre-, event and post- periods for corotating streams are represented by different symbols.

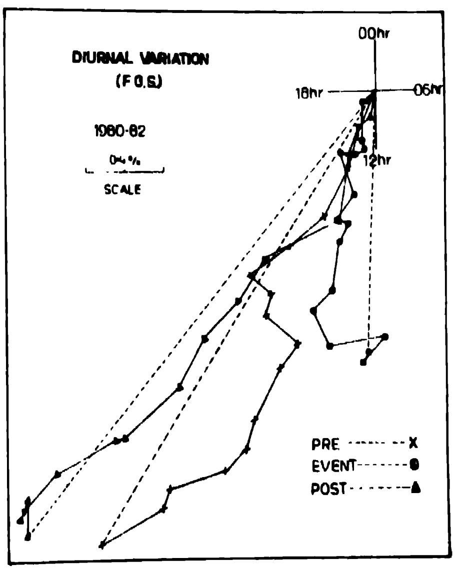

Figure 5. Same as Figure 4, but for flare-generated streams.

Amplitudes and phases of each day, derived from harmonic analysis have been used in Chree analysis. Chree analysis of diurnal anisotropy during the periods of corotating streams do not produce significant changes in its amplitudes and phases. A slight decrease is seen during 4 to 6 days after zero day, which is not sufficient to derive any conclusion. However, phases are shifted to later hours. Similar Chree analysis has been done for flare-generated Streams, as depicted in Figure 3. A significant decrease in average amplitude and phase of diurnal anisotropy is evident during the period of diurnal anisotropy of cosmic ray daily variation. Figure 4 shows the vector addition diagram for diurnal variation events of cosmic ray intensity for the years 1980-1982. Diurnal vectors for pre-event and post-event periods are depicted in the Figure by different symbols. It is seen that the average amplitude of diurnal vectors of cosmic ray daily variation during the period of corotating Streams (event periods) is found less smaller than Pre-event period. Similar vector addition diagram is depicted in Figure 5 for the Flare-generated Streams. It is seen that the average amplitude for event period (Flare-generated Streams period) is found significantly smaller than the average amplitudes of pre- and post-event periods. Average time of maxima for event period is shifted to early hours.

4. Conclusions

On the basis of analysis, it has been found that the diurnal variation of cosmic ray intensity shows day to day variability. The changes have been observed in the amplitude and phase of diurnal anisotropy during the periods of these two types of high speed Solar wind Streams (FGS and CS). However, it is concluded that the Flare-generated Streams are more effective to produce relatively smaller amplitude in diurnal anisotropy of cosmic ray intensity. Further, the time of maximum for diurnal anisotropy shifts towards the early hours.

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